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Running Head: On Subtypes of Developmental Dyslexia

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Abstract

Phonological dyslexics (Ph-DYS) are characterized by a phonological deficit, and surface dyslexics (S-DYS), by an orthographic deficit. Four issues were addressed in this study. First, we determined the proportions of Ph-DYS and S-DYS in a population of French dyslexics by applying the Castles and Coltheart's regression method (1993) to two previously unused diagnostic measures, pseudoword and irregular-word processing time. Thirty-one dyslexics were matched to 19 same-age average readers (10-years-old, CA controls) and to 19 younger children of the same reading level (8-years-old, RL controls). Compared to CA controls, there were more Ph-DYS than S-DYS. Compared to RL controls, there was still a high number of Ph-DYS, whereas the S-DYS profile almost disappeared. Next, we examined the reliability of these subtypes across different measures of phonological and orthographic skills. Compared to RL controls, both groups of dyslexics were found to be impaired only in phonological skills, either in processing time (Ph-DYS) or in accuracy (S-DYS). Then we assessed the moment at which the two dissociated profiles emerged in the course of cognitive development. In order to do so, we examined earlier longitudinal data, collected when the children were 7- and 8-years-old and found that only the S-DYS' orthographic deficit increased with development. Last, we looked at whether the Ph-DYS and S-DYS profiles were associated with other specific cognitive deficits. Specific deficits in phonemic awareness and in phonological short-term memory were found for both Ph-DYS and S-DYS. These data suggested that developmental dyslexia can be largely accounted for by an underlying phonological impairment.

Résumé

La dyslexie phonologique se caractérise par un déficit de la voie phonologique de lecture et la dyslexie de surface par un déficit de la voie orthographique. Le premier objectif de l'étude est d'évaluer la proportion de chacun de ces deux profils chez des enfants francophones. Trente et un dyslexiques de 10 ans ont été appariés à deux groupes contrôle de 19 lecteurs moyens: un de même âge et un de même niveau de lecture (8 ans). Les deux groupes de lecteurs moyens comportent les mêmes enfants, testés à 8 et 10 ans. Les dyslexiques émanent d'une cohorte de pratiquement 400 enfants qui ont été suivis depuis l'âge de 5 ans et les lecteurs moyens d'un sous-groupe de 43 enfants de cette cohorte. Au début de l'étude, ces enfants ne présentaient aucun déficit dans les domaines classiquement répertoriés comme constituant des facteurs de risque pour les apprentissages académiques. Ils ont tous passé à 5, 6, 7 et 8 ans les mêmes épreuves. Toutefois, pour les passations faites à 7 et 8 ans, nous n'avons pu utiliser un ordinateur pour les épreuves de lecture qu'avec les 43 enfants du sous-groupe. A 10 ans, les dyslexiques et les lecteurs moyens ont passé les épreuves de lecture dans la version informatisée. Les profils de dyslexie ont été établis à l'aide de la méthode des regressions mise au point par Castles et Coltheart (1993), en prenant comme indicateur des performances phonologiques et orthographiques les temps de réponse en lecture de pseudomots et de mots irréguliers. La comparaison avec les lecteurs moyens de même âge permet de faire ressortir 16 dyslexiques phonologiques (Ph-DYS) et 10 dyslexiques de surface (S-DYS). Onze Ph-DYS, mais seulement 3 S-DYS, résistent à la comparaison avec les enfants de même niveau de lecture. Le second objectif de l'étude est d'évaluer la fiabilité de cette classification. Dans ce but, on a examiné les scores des différents groupes (les 16 Ph-DYS, les 10 S-DYS, et les deux groupes de lecteurs moyens), dans différentes mesures permettant d'évaluer leurs performances phonologiques et orthographiques: les mesures qui ont servi à typologiser les dyslexiques, plus la précision de la réponse en lecture et en écriture de pseudomots et de mots irréguliers. Les compétences orthographiques de dyslexiques, quel que soit leur type de dyslexie et quelle que soit la mesure utilisée, ne diffèrent pas de celles des enfants de même niveau de lecture. Cette même comparaison fait par contre ressortir un déficit phonologique dans les deux groupes de dyslexiques, soit pour la rapidité de la réponse chez les Ph-DYS, soit pour la précision de cette réponse, en lecture comme en écriture, chez les S-DYS. Le troisième objectif est d'évaluer à partir de quand émergent les profils dissociés. Les données longitudinales recueillies en écriture de pseudomots et de mots irréguliers ont seulement permis de relever que le déficit orthographique des S-DYS est plus fortement marqué lors de la dernière session. Enfin, on a examiné la question de la spécificité des déficits cognitifs des dyslexiques, en dehors de la lecture-écriture. Chez les Ph-DYS, comme chez les S-DYS, des déficits en mémoire à court-terme phonologique (mais pas en mémoire visuelle non-verbale) et en analyse phonémique (mais pas en analyse musicale) ont été relevés. De plus, le déficit en analyse phonémique est observé chez les deux groupes de futurs dyslexiques à 5 ans, avant le début de l'apprentissage de la lecture. Dans leur ensemble, ces résultats indiquent qu'un déficit spécifiquement phonologique peut caractériser et expliquer la dyslexie développementale. Les deux formes de dyslexie ne relèveraient donc pas de profils cognitifs fondamentalement différents. Elles seraient plutôt liées à des stratégies compensatoires différentes, s'expliquant probablement par des facteurs environnementaux.

INTRODUCTION

The search for subtypes of developmental dyslexia should look at the cognitive mechanisms involved in written-word recognition (Castles & Coltheart, 1993; Manis, Seidenberg, Doi, McBride-Chang & Peterson, 1996; Seymour, 1986; Stanovich, Siegel & Gottardo, 1997). These mechanisms can be understood in terms of the dual-route model of reading, which assumes that words are accessed via an orthographic route and a phonological route (e.g., Coltheart, Curtis, Atkins & Haller, 1993; Paap & Noel, 1991). The first route involves direct connections between a written word and its location in the subject's orthographic lexicon. The phonological route involves the use of grapheme-phoneme correspondences. In this model, a deficit in the phonological route is characteristic of phonological dyslexics (Ph-DYS) whereas a deficit in the orthographic route is characteristic of surface dyslexics (S-DYS).

Four goals were set for the present longitudinal study which included different assessments of phonological and orthographic skills (pseudoword versus irregular-word reading processing times and pseudoword versus irregular-word accuracy scores in reading and in spelling). First, we assessed the proportions of Ph-DYS and S-DYS in a population of French dyslexics regarding pseudowords and irregular-word processing times. Second, we examined the reliability of the classification into Ph-DYS and S-DYS using the other measures of phonological and orthographic skills. Third, we tried to find out when dissociated profiles emerged. Fourth, we examined whether Ph-DYS and S-DYS were connected to other specific cognitive deficits, namely, phonemic versus musical awareness and phonological versus visual non-verbal short-term memory.

Case Studies and Group studies of Developmental Dyslexia

Data on acquired dyslexia has played an important role in the dual-route model of reading (Coltheart, Masterson, Byng, Prior & Riddoch, 1983; Coltheart et al., 1993; Morton & Patterson, 1980), since a phonological dyslexia profile with impaired phonological skills and fairly well-preserved orthographic skills has been observed (see the French case reported by Beauvois & Derouesné, 1979), as well as a surface dyslexia profile with impaired orthographic skills and fairly well-preserved phonological skills (e.g., Coltheart et al., 1983). One important question addressed by researchers has been whether these two selective reading-deficit subtypes could be found in developmental dyslexia. Most of the studies involving developmental dyslexics have looked at individual cases (e.g., Campbell & Butterworth, 1985; Hanley, Hastie & Kay, 1992; Temple & Marshall, 1983; Valdois, 1995). Phonological dyslexia is well documented (e.g., Campbell & Butterworth, 1985; Temple & Marshall, 1983), and some cases of surface dyslexia have also been reported (e.g., Coltheart et al., 1983; Hanley et al., 1992).

In the case study method, typical profiles of functional dissociation are examined. One major criticism is that when looking for extreme profiles, mixed profiles that might represent a significant proportion of the dyslexic population are not taken into account. Another problem is that the performance of the cases studied is not compared with that of average readers of the same age and of the same reading level. Lacking such controls, there is a potential risk of wrongly assuming that behavior also found in children who read quite normally for their age (see Bryant & Impey, 1986; Snowling, Bryant & Hulme, 1996) is specific to dyslexia.

In order to determine the relevance of comparing dyslexic with CA and RL controls, think of a two-plate scale with weights on both sides. The left weight represents phonological reading skills and the right weight represents orthographic skills. The total weight of these two skills is of course lower for dyslexics than for CA controls. A further difference is that the two plates may not be balanced in the same manner for dyslexics and CA controls, or in the same manner for all dyslexics: some (Ph-DYS) may exhibit an imbalance with a greater deficit on the phonological-skill side; others (S-DYS) may exhibit an imbalance with a greater deficit on the orthographic-skill side.

In comparing dyslexics (S-DYS or Ph-DYS) and younger RL controls, the total weight of the two reading skills is the same for the two groups. If we find also that the two plates are balanced in the same manner, for example, for S-DYS and RL controls, then we may conclude that S-DYS only exhibit a developmental lag, because they behave like younger RL controls. On the other hand, if the two plates are not balanced in the same manner, for example, for Ph-DYS and RL controls, Ph-DYS results in a pattern that is not observed in average same-level readers. Thus, Ph-DYS appear to deviate from the normal developmental pattern.

The case-study methodology can be adapted to the observation of large samples of dyslexics. This makes it easier to compare Ph-DYS and S-DYS groups to CA and RL controls. The basic principle for classifying dyslexics is to compare their scores with those of CA or RL controls on phonological reading skills (mainly assessed with pseudoword reading) relative to orthographic skills (mainly assessed with irregular-word reading). There are two different methods, which differ in the way the cutoffs are defined.

In the classical method, cutoffs are based on average readers' performance distributions on pseudowords and irregular words. A dyslexic's pseudoword or irregular-word error score (or processing time) is considered indicative of a deficiency if it is more than one standard deviation above the average-readers' mean score. Dyslexics who are impaired for pseudowords without being impaired for irregular words are labelled Ph-DYS. Conversely, dyslexics who are impaired for irregular words without being impaired for pseudowords are labelled

S-DYS (see for example, Castles & Coltheart, 1993; Manis et al., 1996). In this method, the identification of subtypes is based on an <u>selective impairment</u> in phonological or orthographic reading skills. Like Stanovich et al. (1997), we refer to such subtypes as "hard" cases of Ph-DYS or S-DYS, as opposed to "soft" cases, which are based on the observation of a <u>relative deficit</u> in phonological reading skills as compared to orthographic skills, or in orthographic skills as compared to phonological reading skills.

The method used to identify soft cases was first presented by Castles and Coltheart (1993). In this method, cutoffs are based on the regression lines relating pseudoword scores to irregular-word scores in average readers. Cutoffs for pseudoword scores are provided by confidence intervals (CI, 95% or 90%) around the regression line for predicting pseudoword error scores (or processing time) from the corresponding irregular-word baseline scores in the average-reader reference sample. Inversely, cutoffs for irregular-word scores are given by the CI which predicts the irregular-word error scores (or processing time) from the corresponding pseudoword scores. A dyslexic with a pseudoword error score (or processing time) above the upper CI limit of average readers when the pseudoword score is predicted from the irregular-word score is classified as deficient in pseudoword reading. Inversely, a dyslexic who exhibits an irregular-word error score (or processing time) above the upper CI limit of average readers when the irregular-word score is predicted from the pseudoword score is classified as deficient in irregular-word reading. Finally, dyslexic profiles are determined in the conventional way. Dyslexics classified as deficient in pseudowords only are called Ph-DYS and those classified as deficient in irregular words only are called S-DYS.

The classical method and the regression-based method have been used in various studies on both English dyslexics (Castles & Coltheart, 1993; Manis et al., 1996; Stanovich et al., 1997) and French dyslexics (Genard, Mousty, Content, Alegria, Leybaert & Morais, 1998). In the studies that applied the classical method, more than half of the dyslexics had both deficits compared to CA controls. The number of hard Ph-DYS and S-DYS cases identified was low (between 20% and 32%). However, the relative proportions of each of the hard subtypes differed across languages. In English, the proportions of Ph-DYS and S-DYS were found to be almost the same (9.8% vs. 9.8% and 15% vs. 17% in the Manis et al. and Castles & Coltheart studies, respectively). In the French study, fewer Ph-DYS than S-DYS were found (less than 3% vs. 23%, respectively).

In the studies where the regression-based method was applied, the proportion of dyslexics exhibiting dissociations between phonological and orthographic skills was larger, but language differences remained. In the English studies, there were more soft Ph-DYS than soft S-DYS profiles: 54.7% vs. 30.2% in Castles & Coltheart (1993), 33.3% vs. 29.4% in Manis et al. (1996), and 25% vs. 22.1% in Stanovich et al. (1997). In the French study (Genard et al., 1998), a very small proportion of soft Ph-DYS was found (4% vs. 56% for soft S-DYS). Moreover, except in the Stanovich et al. study, where 27.9% of the dyslexics were impaired both in phonological and in orthographic reading skills, less than 10% of the dyslexics had both deficits. For the reading-level comparisons, the most striking finding in these studies was that the number of soft Ph-DYS remained high, whereas the S-DYS profile almost disappeared.

These trends were based solely on measures used to classify dyslexics into subtypes (namely pseudoword and irregular-word accuracy). In some of the reviewed studies (Manis et al., 1996; Stanovich et al., 1997) other measures of phonological and orthographic skills were used. In these studies, the S-DYS's orthographic skills were not found to be inferior to those of RL controls, regardless of what measure was used (Manis et al., 1996). Comparisons between Ph-DYS and RL controls were very different from those involving S-DYS. For example, in the Stanovich et al. study (1997), two pseudoword reading measures and one phonological sensitivity measure showed that Ph-DYS had a significant deficit compared to RL controls. Similar trends were observed in the Manis et al. study (1996). The S-DYS profile thus seems to correspond to a developmental lag, insofar as soft S-DYS appear to perform similarly to younger RL controls, whereas soft Ph-DYS deviate from the normal developmental pattern.

<u>Limitations of Studies Showing Soft Cases of Ph-DYS and S-DYS</u>

Discrepancies between the results of the English and French studies could be due to two factors. First, because English spelling is less transparent than French spelling (see Sprenger-Charolles, in press), English-speaking children may have more trouble than French-speaking children overcoming the obstacles encountered in mastering the phonological reading route. In this light, it is not surprising to find a larger number of Ph-DYS in English than in French. Second, the French- and English-speaking children were not selected on the basis of the same criteria. In the Genard et al. study (1998), overall reading skills were assessed through a reading comprehension test that required the silent reading of sentences. The match between dyslexics and younger RL controls was established on the basis of this task, and not on the basis of their word-reading level. In fact, French-speaking dyslexics obtained lower scores than the younger RL controls in regular and irregular-word reading, whereas English-speaking dyslexics were matched to RL controls on word reading (Manis et al., 1996; Stanovich et al., 1997).

Differences in dyslexics' chronological ages may account for discrepancies among the English studies. As suggested by Stanovich et al. (1997), the large proportion of dyslexics showing both deficits in their own study might be due to the fact that their dyslexics were younger (9-years-old) than in the other two English studies (11-years-old in Castles & Coltheart, 1993; 12-years-old in Manis et al., 1996). As Stanovich et al. argued, some young dyslexics "in the both deviant group might continue to practice reading and to receive considerable exposure to print (...). This print exposure may result in these children having relatively less seriously impaired orthographic processing mechanisms (...). However, their more seriously impaired phonological processing abilities will probably not develop at the same rate (...), thus resulting in greater dissociation between phonological coding ability and exception word fluency with development" (Stanovich et al., 1997, p.124). This could cause a greater number of dissociated profiles, especially Ph-DYS, among older dyslexics than among younger ones. This was observed in the English studies where the dyslexics were about 11 (Castles & Coltheart, 1993) or 12 (Manis et al., 1996). However, in both of these studies, the age range was broad in the dyslexic samples. More than 6 years separated the youngest dyslexics from the oldest ones, who were 15-years-old. Thus, the data could conceal strong differences among the ages considered. This criticism also holds for the French study (Genard et al., 1998) on 10-year-old children where there was a gap of three years between the youngest (age 9) and oldest (age 12) child.

One explanation of the S-DYS profile would be that poor performance on irregular words is due to a lack of print exposure, since word-specific knowledge is normally acquired by reading (Stanovich et al., 1997). Another explanation is related to a visual perception deficit. This type of deficit, which results in low quality input to the reading system, can be expected to have an impact on learning to read for all types of letter strings, with irregular words being the most vulnerable (Manis et al., 1996). A final account would be that S-DYS only exhibit a developmental lag in reading (Manis et al., 1996; Stanovich et al., 1997). In the studies we reviewed, the first two hypotheses cannot be verified since these studies included neither print exposure assessments nor visual perception tests. On the other hand, as already noted, the finding that S-DYS perform similarly to younger RL controls (Genard et al., 1998; Manis et al., 1996; Stanovich et al., 1997) suggests that these children only suffer from a developmental lag.

The main explanation of the Ph-DYS profile is that these children suffer from a <u>specific</u> phonological impairment that causes their performance to deviate from that of CA and RL controls (Castles & Coltheart, 1993; Manis et al., 1996; Stanovich et al., 1997). This impairment is thought to be rooted in a deficiency in the phonological reading route, which results from an initial deficit in the children's phonological skills. In two of the studies we reviewed, Ph-DYS were found to suffer from a phonological deficit in nonreading tasks such as phonological awareness, both relative to S-DYS (Manis et al., 1996) and to RL controls (Manis et al., 1996; Stanovich et al., 1997). Thus, the phonological deficit of these Ph-DYS was severe. However, in these studies, performance on tasks that involved the phonological processor was not compared with performance on similar tasks that did not involve this processor. Moreover, longitudinal data was not collected. Thus, these studies do not clarify the issues of the specificity of the phonological deficit and its origin.

<u>The Phonological Deficit in Developmental Dyslexia</u>

There is considerable support for the view that a phonological reading disability is quite common in developmental dyslexia (for English-speaking children: Rack, Snowling & Olson, 1992; Siegel, 1993; Stanovich & Siegel, 1994; for French-speaking children: Sprenger-Charolles & Casalis, 1996; for German-speaking children: Wimmer, 1993; 1996) as are deficits in nonreading tasks that tap phonological skills (Bruck, 1992; Mann & Liberman, 1984). More precisely, developmental dyslexia is thought to be associated with an impairment in two main phonological skills related to learning to read, namely, phonemic awareness and phonological short-term memory. Phonemic awareness and reading level are thought to be linked because alphabetic writing systems transcribe the phonemic speech string more or less directly. Thus, in order to learn to read, one has to connect the graphic units (graphemes) with their phonemic counterparts (phonemes). Being able to make this connection implies some kind of phonemic awareness. Also, memory skills may be particularly critical for using the phonological reading route, since the result of the grapheme-to-phoneme conversion on each word segment must be held in short-term memory while the remaining segments of the word are processed. Deficits in phonemic awareness and in phonological short-term memory are thus assumed to account for difficulty in reading acquisition.

However, longitudinal studies have failed to provide strong evidence that <u>early</u> differences in phonological short-term memory contribute to differences in reading, once differences in other phonological skills are factored out (Lecocq, 1991; Wagner, Torgesen & Rashotte, 1994). On the other hand, phonemic awareness has proven to be one of the strongest predictors of later reading skills. This finding has been obtained for different alphabetic systems (English children: Bradley & Bryant, 1978; Mann, 1993; Mann & Liberman, 1984; Scandinavian children: Lundberg, 1982; Lundberg & Hoien, 1989; French children: Lecocq, 1991). In addition, phonemic awareness has been shown to be one of the most consistent deficits in dyslexic children and adults (Bruck, 1992). For example, in a number of studies, disabled readers obtained lower scores on phonological awareness tasks, and especially on phonemic awareness tasks, than CA controls (English-speaking children: Fawcett & Nicolson, 1994; McDougall, Hulme, Ellis & Monk, 1994; German-speaking children:

Wimmer, 1993) and than younger RL controls (English children: Fawcett & Nicolson, 1994; French children: Lecocq, 1991). Furthermore, before beginning to learn to read, children who would later become dyslexic have been shown to exhibit impaired phonemic awareness (Lundberg & Hoien, 1989; Wimmer, 1993, 1996).

Finally, some studies have suggested that the deficit in dyslexics is specific to phonological awareness relative to musical awareness, for example (Morais, Cluytens & Alegria, 1984), and specific to phonological short-term memory relative to visual, nonverbal short-term memory, for example (Brady, Shankweiler & Mann, 1983; Liberman, Mann & Werfelman, 1982; Mann & Liberman, 1984; McDougall et al., 1994; Rapala & Brady, 1990). In the Morais et al. (1984) study, dyslexics did not differ from CA controls in musical segmentation, whereas they were considerably worse in phonemic segmentation. In the same study, low correlations between reading and musical segmentation but strong correlations between reading and phonemic segmentation were observed. Hence, the sound-analysis deficit of dyslexics does seem to be specifically linguistic in nature. Similar findings have been obtained for phonological short-term memory relative to visual (nonverbal) short-term memory (Brady et al., 1983; Liberman et al., 1982; Mann & Liberman, 1984; McDougall et al., 1994; Rapala & Brady, 1990).

Unfortunately, in all of these studies, dyslexics were taken as a group, not according to their different profiles, making it impossible to know whether phonological awareness and phonological short-term memory deficits are specifically related to the Ph-DYS profile. One can expect Ph-DYS to exhibit specific phonological deficits, particularly in phonemic awareness and in phonological short-term memory, whereas S-DYS should show specific deficits in visual short-term memory that would prevent them from acquiring the orthographic pattern of words.

Overview of the Present Study

Four main issues were addressed in this study. First, we determined the proportions of Ph-DYS and S-DYS in a population of French dyslexics by applying the regression method to two previously unused diagnostic measures, pseudoword and irregular-word processing time. Next, we examined the reliability of the subtypes obtained with this method across different measures of phonological and orthographic skills. Then we assessed the moment at which the two dissociated profiles emerged in the course of cognitive development. Last, we looked at whether the Ph-DYS and S-DYS profiles were associated with other specific cognitive deficits.

This study replicated the studies by Castles and Coltheart (1993), Genard et al. (1998), Manis et al. (1996), and Stanovich et al. (1997) except that we tried to overcome some of their limitations. As in all of the above English studies (but not the French study), the dyslexics were matched to RL controls on the basis of their word-reading scores. As in the Stanovich et al. study, our sample did not vary widely in age (less than 11 months between the youngest and oldest child).

Subtypes were identified using the regression method on pseudoword and irregular-word processing time. Because there is a normal amount of variation associated with performance on a given measure, as well as a possible measurement error, it is important to establish the reliability of the observed differences on a given measure across different assessments of the same skill (see Manis et al., 1996). To do this, we used validation measures suited to the two hypothesized reading deficits and then compared the results obtained with our validation measures to those obtained with the subject-classifying measure (the "defining" measure, see Manis et al., 1996). For phonological-skill assessment, we therefore relied not only on the defining measure (pseudoword processing time), but also on pseudoword reading and spelling accuracy scores. Similarly, to assess orthographic skills, we relied not only on the defining measure (irregular-word processing time) but also on irregular-word reading and spelling accuracy scores. Thus, our battery included a variety of measures that could provide some converging validation for the subtypes.

Our study differed also from the above studies because we relied on longitudinal data collected before establishing the subtypes. The earlier longitudinal data included assessments of phonological and orthographic spelling skills. In line with Stanovich et al. (1997), we can hypothesize that dissociated profiles only emerge later, with phonological impairment showing up in Ph-DYS and orthographic impairment showing up in S-DYS. Furthermore, to find out whether the Ph-DYS and S-DYS profiles were associated with other specific cognitive deficits, we assessed the children's nonreading phonological skills relative to similar non-phonological skills, namely, phonemic vs. musical awareness and phonological vs. visual short-term memory. A specific phonological deficit was hypothesized for Ph-DYS, and a specific visual short-term memory deficit that would prevent orthographic word-pattern acquisition was hypothesized for S-DYS.

METHOD

Participants

The dyslexics were selected among a large cohort of children (approximately 400) followed from kindergarden (age 5) to the end of grade 2 (age 8); the control group of average readers was selected among a subgroup of 60 children from the same cohort. The main difference between this subgroup and the other children was that we used computer-run reading tasks only for the subgroup between the ages of 6- to 8-years-old. To participate in the study, the children had to meet the following criteria: (a) 5-year-old nonreaders and native French speakers who were not from an underprivileged home, (b) no language, motor, or psychological disorders and (c) average or above average nonverbal and verbal IQs. Nonverbal IQ was assessed using Raven's matrices (Raven, 1976) and verbal IQ was measured by a standardized French vocabulary test (Deltour & Hupkens, 1980) for 5- to 8-years-old. We were able to follow 373 of these children until the age of 8. These children were still nonreaders at the end of kindergarten (age 6). Inability to read was assessed on the Bat-Elem reading test (Savigny, 1974), a standardized test for children between the ages of 6 and 9.

At age 8, 52 children out of the 373 were classified as below-average readers; their Bat-Elem reading scores were at least one standard deviation below the cohort mean. We continued to follow these children. Two years later, 45 below-average readers remained. Among them, we selected the 33 children whose reading level was severely impaired; their scores were more than two standard deviations below the mean on the reading-aloud subtest of the ANALEC (Inizan, 1995), a standardized test for fourth grade (age 10).

When they were 10 years-old, 43 of the 60 children of the subgroup remained[1]. Out of these 43 children, 10 were classified as above-average readers, 19 as average, and 14 as below-average according to their scores on the reading-aloud subtest of the ANALEC. To enable comparison between severely-impaired readers with readers who showed normal reading performance, only the average readers were included in the control group. These average readers were used both as chronological-age controls (comparison with the dyslexics of the same age, CA controls), and as reading level controls (comparison with the dyslexics of the same reading level, RL controls). This design allowed us to avoid biases due to uncontrolled differences between the CA and the RL control groups.

To constitute the RL control group, we compared the scores obtained on a word-reading and a word-spelling task (see below) by the 10-year-old severely-impaired readers to those of the average readers when they were 8 years-old. According to the results of two-tailed t-tests, the word-reading scores of 31 out of the 33 severely-impaired readers did not differ from those of the younger 19 average readers in accuracy or processing time. There was also no significant difference between these two groups on word-spelling accuracy. Thus, the 8-year-old average readers (11 boys and 8 girls) can be considered as RL controls for the 10-year-old severely-impaired readers (20 boys and 11 girls). Concerning the CA controls, no difference was found between the severely-impaired readers and the average readers for chronological age. Moreover, in kindergarten, these two groups did not differ on nonverbal and verbal IQs. The criteria we used to choose the severely-impaired readers were thus the same as those used to select dyslexics, except that their nonverbal and verbal IQs were assessed before the beginning of reading instruction. Then, these children were considered to be dyslexics. The test results characterizing the groups are presented in Table 1 (Chronological Age, Reading and Spelling Levels, Nonverbal and Verbal IQs).

Concerning the school and social environment, the 373 kindergartners were from 19 different schools in the Parisian area. One, two, or sometimes three of the 31 dyslexics came from the same school. The methods used to teach reading in the first grade in these schools, as in most French schools (see Béchennec & Sprenger-Charolles, 1998), were a mixture of the "analytical" approach (focusing on simple vowels and consonants in nonsense syllables and words) and the "global method" (use of key words and short texts). There was no significant socio-economic status difference between the 31 dyslexics and the 19 average readers. Based on the occupation of the head-of-household, 63% of the average readers and 61% of the dyslexics were from upper-middle-class backgrounds (middle and senior managers), and 37% and 39%, respectively, had middle- and lower-middle-class backgrounds (office workers, shopkeepers, craftsmen, semi-skilled workers and unskilled workers).

Materials and Procedure

Participants were tested in a quiet school room. The first test session, held when the children were 5 years-old, took place between November and December. When they were 7, 8, and 10, the test sessions took place at the end of the school year, during the months of May and June. The children were tested individually, except for the spelling tasks.

Nonverbal and Verbal IQs. Nonverbal IQ was assessed using Raven's matrices (Raven, 1976). In each of 36 trials, the child had to find the missing piece among six different pieces in order to complete a visuo-spatial pattern. The total number of correct responses (maximum = 36) was scored for each child. Verbal IQ was measured using an oral French vocabulary test (Deltour & Hupkens, 1980) designed for 5- to 8-years-old. Given six pictures, the child was instructed to pick the one that corresponded to a spoken target word. One of the pictures was the best representation of the word, for example, the picture of a castle for the word "castle" (château); another alternative was not wrong but was not as good (a big house). The remaining alternatives were incorrect: a cat (chat), a cake (gâteau), a king (roi), and an air control tower (tour de contrôle). The maximum score per test item was two points. Two points were given if the child selected the correct alternative and one point if he/she selected the next-best picture. Thirty words were used (18 nouns and 12 verbs). Nonverbal and verbal IQs were assessed when the children were 5 years-old.

Standardized Reading Tests. Two standardized reading tests were used to assess reading level. The first was the Bat-Elem (Savigny, 1974), a standardized test for first to third graders (ages 6-9). First, reading-aloud accuracy was tested on 40 target syllables (20 isolated nonsense syllables and 20 syllables embedded in words in a text). The children who were able to read more than 30 of the 40 target syllables were then asked to read two short texts aloud on which reading time and errors were recorded. A reading score was calculated based on reading time to which 5 seconds per error was added. This test was administered when the children were 6 and 8 years-old. The second reading test was the text reading-aloud subtest of the ANALEC A2 (Inizan, 1995), a standardized test for fourth graders (age 10). As with the Bat-Elem, reading time and errors were recorded; the reading score was the reading time plus 5 seconds per error. This test was administered when the children were 10-years-old (CA controls).

Word Reading Tasks. A word-reading task was used to match the 10-year-old dyslexics to the 8-year-old average readers. We selected 48 words with four different levels of grapheme-phoneme consistency (12 words per level). At the first level, the grapheme-phoneme correspondences were simple and regular; the second-level words included context-independent bigraphs such as "ou" /u/; the third-level words included context-dependent graphemes such as "c" and "g"; the fourth-level words were irregular and contained either a low frequency grapheme (i.e. a grapheme with a peculiar pronunciation such as the "e" in femme /fam/) or a silent grapheme in a non-terminal position (like the p in sept /set/). The 48 words were very common in French: all were included in the Listes Orthographiques de Base (Catach, 1984) and/or in the Dictionnaire Fondamental (Gougenheim, Michéa, Rivenc & Sauvageot, 1964). The words are listed in the Appendix.

We took into account both accuracy and processing time for correct responses. The procedure was as follows. The child was asked to read aloud each item that appeared on a PC computer monitor. Each word remained on the monitor until the end of the child's response. Recordings, which began when the stimulus appeared on the monitor, were made with a Sound Blaster board in the computer. The speech signal was edited using the Sound Blaster's Creative Voice Editor. Processing time was calculated from stimulus onset to the beginning of the first speech signal corresponding to the response. Correct responses and errors were also scored during the test session and were later reexamined from recordings. The total number of correct responses (maximum = 48) was scored for each child. The average readers at ages 7, 8, 10 and the dyslexics at age 10 completed the word-reading task using this procedure. At ages 7 and 8, the dyslexics were given the same task, but for most of them without a computer. Only the data collected using the same methodology is reported here, that is, the reading performance of the 10-year-old dyslexics and of the CA and RL controls (ages 10 and 8).

Word Spelling Task. In addition to the word-reading task, a word-spelling task was also used to match the 10-year-old dyslexics to the 8-year-old average readers. The same 48 words were used for both reading and spelling. The word-spelling task was administered after the word-reading task to prevent the children from having an auditory image of the items before the reading task. Test items were dictated to small groups of children. Because of the risk of confusion between homophones, the words were first read in a sentence. The total number of correct responses (maximum = 48) was scored for each child. We report the performance of the 10-year-old dyslexics and of the CA and RL controls.

Orthographic vs. Phonological Reading Skills. Orthographic and phonological reading skills were assessed in order to identify the specific deficit of dyslexic children. For these assessments, we relied partially on the word-reading data (see above). More precisely, to assess orthographic skills, we relied on the reading of the 12 irregular words from the 48-word-list. The phonological-skill measure was the reading of pseudowords. Two lists of pseudowords were generated. These pseudowords were analogically unrelated to words. The first list included 4 items with only simple and regular graphemes, 4 with one context-independent bigraphs (such as "ou"), and 4 with one context-dependent graphemes (such as "g"). The 12 pseudowords in the second list each contained 6 simple graphemes. Four items were composed of three CV syllables, four of two CVC syllables, and four of one CCV syllable plus one CVC syllable. The items on the two pseudoword lists were presented in a mixed order in one test session. The pseudowords are presented in the Appendix. Both accuracy and processing time for the 12 irregular words vs. the 24 pseudowords were taken into account. The procedure was the same as for the word-reading task (see here above), except that the analysis for accuracy was based on the mean percentage of correct responses. The word-reading task (including irregular words) was administered before the pseudoword-reading task. We report the data for the 10 year-old dyslexics and for the CA and RL controls.

Orthographic vs. Phonological Spelling Skills. Orthographic and phonological spelling skills assessments were also used to examine the specific deficit of dyslexic children. For these assessments, we relied partially on the word-spelling data (see here above). To assess orthographic skills, we examined accuracy scores for the spelling of the 12 irregular words from the 48 word list. Accuracy scores in the spelling of 24 pseudowords (the same as those used to assess reading phonological skills) was the phonological-skill measure. The word-spelling task (including irregular words) was administered before the pseudoword-spelling task. The procedure was the same as for the word-spelling task, except that, first, pseudowords were read two times (and not in a sentence), and, second, the analyses were based on the mean percentage of correct response. Using the same methodology, the children performed these spelling tasks at ages 7, 8, and 10. However, the third-level words and pseudowords were only included when the children were 8 and 10-years-old. All these spelling longitudinal data are reported below.

. Phonological vs. Visual Short-Term Memory. To test phonological short-term memory, the children were asked to repeat 24 pseudowords that differed in syllable length (three to six syllables). There were six pseudowords for each syllable length, half of which contained only CV syllables (e.g., favéli, gontadiro, tabaritolu, pédonuratilé), and half of which included one CVC syllable (e.g., bartino, rikalpéta, tirsatabito, toziltéfavilo). The stimuli were pre-recorded. The score was the number of syllables (3 to 6) in the last series in which the child succeeded at least four times. Visual short-term memory was assessed with the Corsi test (see Hitch, Haliday, Schaafstal, Marten & Schraagen, 1988). The experimenter defined a path by pointing in succession to two to seven blocks. The child had to reproduce this path. There were three series for each length. The score was the number of blocks (2 to 7) in the last serie on which the child succeeded at least twice. Phonological memory was assessed when the children (dyslexics and control groups) were 8 and 10 years-old and visual memory only when they were 10 years-old.

Phonemic vs. Musical Awareness. The phonemic awareness task involved the deletion of the first phoneme of 10 CV and 10 CVC pseudowords (CV: nan, zon, ja, bi, chon, kin, zu, na, ji, da; CVC: vour, buf, kir, saf, vul, fal, gur, zek, nol, bap). The pseudowords were supposed to prevent biases resulting from the children's vocabulary knowledge. To determine whether the deficit in phonemic awareness was specific to speech, we assessed the children's musical awareness. A same-different paradigm for 18 pairs of sung melodies of three-note each was used. Six of the 18 pairs were identical. Six differed solely by contour (low-high-low vs. high-low-high), four by register (upper vs. lower, middle vs. upper, middle vs. lower), and two by both register and contour. For the phonemic and musical awareness tasks, the items were pre-recorded. The total number of correct responses was scored for each child (maximum, 20 for phonemic awareness; 18 for musical awareness). These two tasks were given to all the children enrolled in the study when they were 5, 7, and 8 and not later because of possible ceiling effects.

RESULTS

Hard and Soft subtypes

Hard cases of Ph-DYS and S-DYS

To identify hard Ph-DYS and S-DYS cases, we used the classical method with the usual criterion of one SD below the mean accuracy score of CA controls (or above the mean for processing time). For accuracy, out of the 31 dyslexics, 24 were deficient in pseudoword reading, 27 were deficient in irregular-word reading, 21 had both deficits, and 1 had neither. Only 3 children were selectively impaired in pseudoword reading (Ph-DYS) and 6 were selectively impaired in irregular-word reading (S-DYS). Thus, only 9 of the 31 dyslexics had a selective deficit (29%).

Using the classical method on processing time, 21 of the 31 dyslexics were slow in pseudoword reading, 22 were slow in irregular-word reading, 16 had both deficits, and 4 had neither deficit. Only 5 children were selectively slow in pseudoword reading (Ph-DYS) and 6 were selectively slow in irregular-word reading (S-DYS). Thus, a selective deficit was found in only 11 of the 31 dyslexics (35%). When both accuracy and processing time were considered, only 2 dyslexics had a selective impairment (2 S-DYS).

Soft cases of Ph-DYS and S-DYS

We used the regression method but only on processing time because irregular-word accuracy reached a ceiling level for CA controls (3 made only two mistakes, 7 made only one, and the other 9 made none). Thus, the estimated regression coefficient was biased towards higher values. This is a drawback for using the regression coefficient for classification purposes.

We first examined the relationship between pseudoword and irregular-word processing time in the same-age groups (10-years-old). Regression of irregular-word reading over pseudoword reading was performed for the 19 CA controls so as to estimate the expected number of correctly-read pseudowords at varying levels of irregular-word reading, and vice versa. Confidence intervals were set at 95% using the scores of CA controls for regression of irregular-word reading over pseudoword reading, and for regression of pseudoword reading over irregular-word reading. The performance plots of the dyslexics were then superimposed on those of the CA controls to identify the Ph-DYS and S-DYS subjects. Sixteen soft Ph-DYS were found (10 boys and 6 girls). These subjects, shown in Figure 1 as filled-in squares, fell outside the confidence limits for pseudoword reading relative to their irregular-word reading level but were within the normal range for irregular-word reading relative to their pseudoword-reading level. Ten children shown as filled-in squares in Figure 2 were outliers on irregular-word reading, but were within the normal range on pseudoword reading, thus exhibiting a soft S-DYS profile (8 boys and 2 girls). Finally, one child was found to be an outlier on pseudowords and irregular words alike, and four were in the normal range on both assessments.

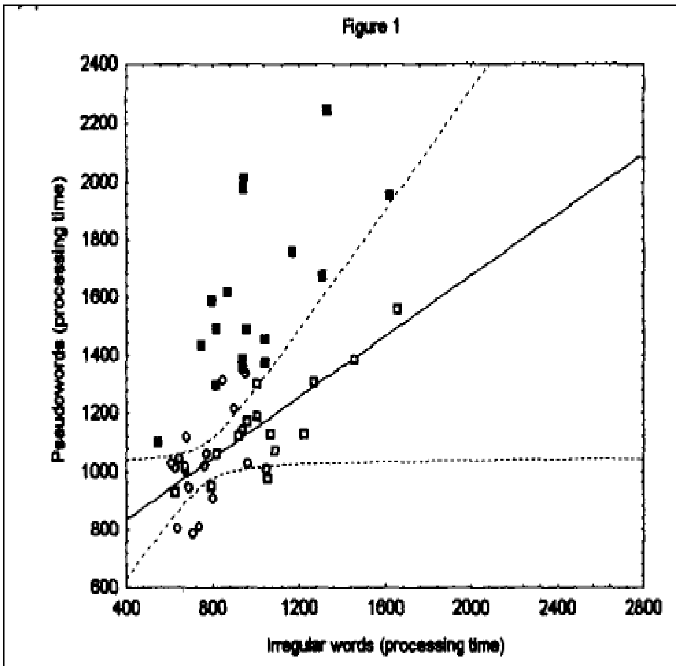


Figure 1. Pseudoword processing time plotted against irregular-word processing time for dyslexics (squares). The regression line and confidence intervals (95%) were derived from the data for average readers of the same chronological age (circles). Phonological dyslexics are shown as filled-in squares, and dyslexics with both deficits, as crossed-out squares.

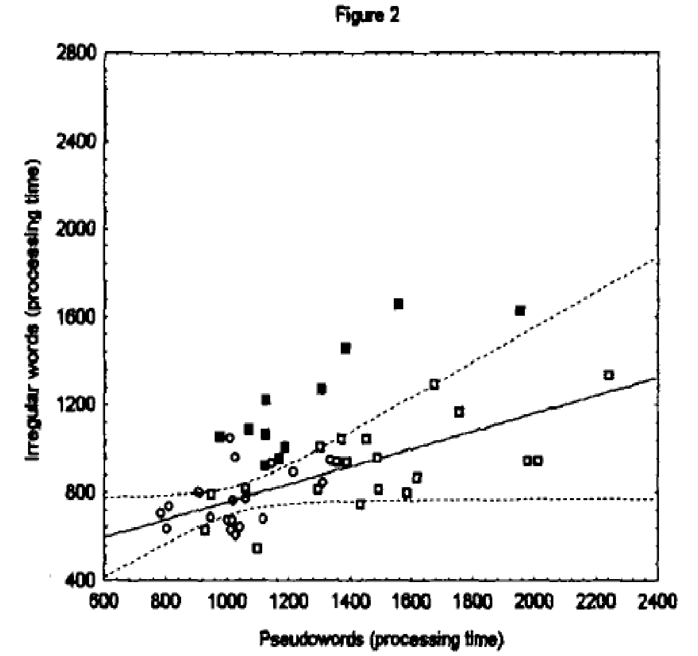
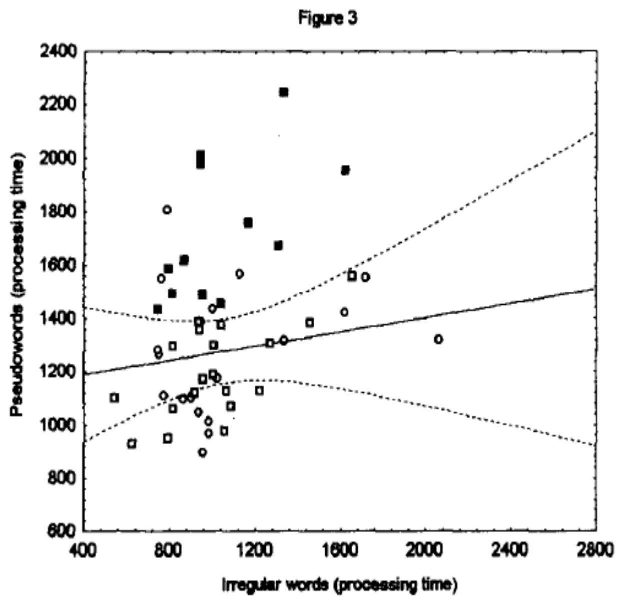


Figure 2. Irregular-word processing time plotted against pseudoword processing time for dyslexics (squares). The regression line and confidence intervals (95%) were derived from the data for average readers of the same chronological age (circles). Surface dyslexics are shown as filled-in squares, and dyslexics with both deficits, as crossed-out squares.

The same analyses were run for children matched on reading level. The results are shown in Figures 3 and 4. The regression line and confidence intervals are based on the data from the nineteen 8-year-old RL controls (95% confidence interval). Circles stand for RL controls and squares, for dyslexics. Filled-in squares are the Ph-DYS (Figure 3) and the S-DYS (Figure 4). Eleven of the 16 Ph-DYS as revealed by the chronological-age comparison could still be classified as such (7 boys and 4 girls). These children fell outside the confidence limits on pseudowords but within the normal range on the other plot. Only 3 of the 10 S-DYS still fell outside the confidence limits on irregular words but were within the normal range on the other plot (2 boys and 1 girl).



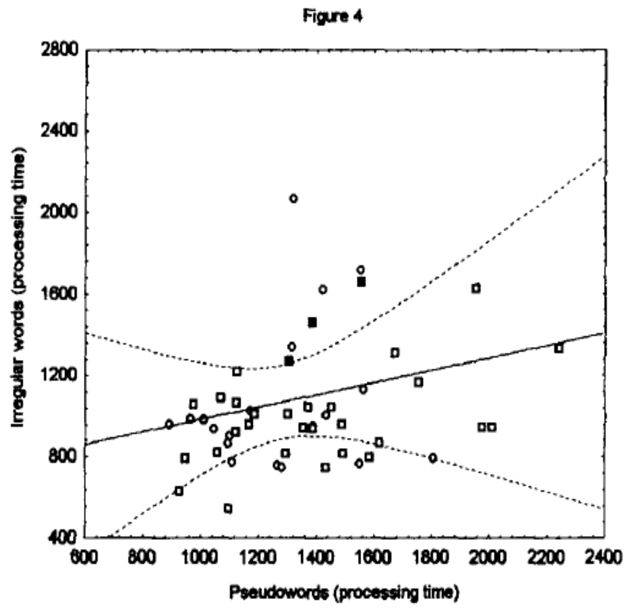


Figure 3. Pseudoword processing time plotted against irregular-word processing time for dyslexics (squares). The regression line and confidence intervals (95%) were derived from the data for average readers of the same reading level (circles). Phonological dyslexics are shown as filled-in squares, and dyslexics with both deficits, as crossed-out squares.

Figure 4. Irregular-word processing time plotted against pseudoword processing time for dyslexics (squares). The regression line and confidence intervals (95%) were derived from the data for average readers of the same reading level (circles). Surface dyslexics are shown as filled-in squares, and dyslexics with both deficits, as crossed-out squares.

The test results characterizing the 16 Ph-DYS and the 10 S-DYS that emerged from the regression method are shown in Table 1 (Chronological Age, Reading and Spelling Levels, Nonverbal and Verbal IQs). According to the results of two-tailed t-tests, Ph-DYS and S-DYS were comparable in word-reading accuracy and processing time. Ph-DYS did not differ from the younger RL controls in word-reading accuracy and processing time. S-DYS did not differ from the same control group in word-reading processing time, however, they read fewer words correctly, t (27) = 2.26, $p < .05$. For age and nonverbal IQ, no significant differences were found between the different groups. For verbal IQ, S-DYS lagged behind both Ph-DYS and same-age average readers, t(24 and 27) = 2.29 and 2.67, all ps < .05 (differences without a significance level were significant at $p < .01$ or better).

Table 1.
Means (and Standard Deviations) for Dyslexics and Comparison Groups: Chronological Age, Reading and Spelling Levels, Nonverbal and Verbal IQs

	CA Controls[a] n = 19	RL Controls[a] n = 19	Dyslexics[b] n = 31	S-DYS[b] n = 10	P-DYS[b] n = 16
Chronological Age	120.16	96.16	118.94	119.70	118.19
(in months)	(3.2)	(3.2)	(3.5)	(3.9)	(3.2)
ANALEC Reading	60.63		137.55	149.70	130.69
Time (in sec.)	(7.3)		(38.3)	(38.0)	(30.8)
Word Reading	766.89	999.63	1006.55	1063.30	975.31
Time (ms.)	(124)	(274)	(210)	(165)	(216)
Word Reading	46.89	44.11	42.71	42.20	43.19
Accuracy	(1.1)	(1.8)	(2.9)	(2.7)	(2.9)
Word Spelling	44.05	35.74	36.35	34.00	37.81
Accuracy	(2.8)	(4.5)	(4.8)	(3.3)	(4.2)
Nonverbal IQ[c]	17.63		16.42	16.90	15.81
	(2.0)		(3.7)	(2.1)	(3.5)
Verbal IQ[c]	41.00		38.61	36.00	40.31
	(5.3)		(4.9)	(3.7)	(5.2)

a. CA and RL Controls were the same children, tested when they were 10 years-old (CA Controls) and 8 years-old (RL Controls)
b. 10-year-old Dyslexics
c. These scores were those obtained by the children in the first test session, when they were 5-years-old.

The results for pseudoword and irregular-word processing times are presented in Table 2. Ph-DYS and S-DYS differed, as expected, on the defining measure. Ph-DYS read pseudowords more slowly than S-DYS, t(24) = -3.63. S-DYS read irregular words more slowly than Ph-DYS, t(24) = -2.53, $p < .05$. Both Ph-DYS and S-DYS lagged behind CA controls for pseudoword and irregular-word processing time, t(33 and 27) = -7.04 and -2.79 vs. -3.15 and -5.89. Ph-DYS did not differ from the younger RL controls in irregular-word processing time, but they read pseudowords more slowly, t (33) = -3.29. S-DYS did not differ from the same control group in reading processing time for irregular words and pseudowords.

The results for pseudoword and irregular-word accuracy scores are presented in Table 2. None of the differences between Ph-DYS and S-DYS were significant whereas these two groups of dyslexics read pseudowords and irregular words less well than CA controls, t(33 and 27) = 3.97 and 4.88, for pseudowords, 4.94 and 6.6, for irregular words. Neither Ph-DYS nor S-DYS obtained a lower score than the younger RL controls for irregular words, but an unexpected poorer score on pseudowords was observed for S-DYS, t(27) = 2.64, $p < .05$.

Table 2.
Means (and Standard Deviations) for Dyslexics and Comparison Groups: Orthographic and Phonological Reading skills, Phonological and Visual Short-Term Memory

	CA Controls[a] n = 19	RL Controls[a] n = 19	S-DYS[b] n = 10	Ph-DYS[b] n = 16
Irregular-Word Reading	771.53	1068.42	1170.40	951.00
Time (ms.)	(133)	(363)	(234)	(202)
Irregular-Word Reading	**94.30**	**75.87**	**73.33**	**77.60**
Accuracy (mean %)	(6.24)	(9.17)	(10.97)	(13.17)
Pseudoword Reading	1031.00	1278.68	1202.80	1577.19
Time (ms.)	(151)	(241)	(168)	(296)
Pseudoword Reading	90.14	83.33	71.67	80.47
Accuracy (mean %)	(5.05)	(8.67)	(15.19)	(9.09)
Short-Term Memory	4.95	4.84	3.40	3.75
Phonological span	(0.97)	(0.83)	(1.17)	(0.77)
Short-Term Memory	5.16	-------	4.90	4.88
Visual span	(0.76)		(0.88)	(0.96)

Note. Dashes indicate that the task was not administered
a. CA and RL Controls were the same children, tested when they were 10 years-old (CA Controls) and 8 years-old (RL Controls)
b. 10-year-old Dyslexics

Discussion. In the comparison with CA controls, the regression method pointed out 16 soft Ph-DYS profiles and 10 soft S-DYS profiles. Relative to RL controls, most of the Ph-DYS (11 out of 16) remained, whereas most of the S-DYS (7 out of 10) disappeared. Thus, the S-DYS profile seems to correspond to a developmental lag, in that most of the soft S-DYS were found to perform similarly to younger RL controls. The results of the t tests corroborated these trends. Ph-DYS differed from S-DYS, and S-DYS differed from Ph-DYS, only on the defining measures (pseudoword or irregular-word processing time). Relative to CA controls, Ph-DYS and S-DYS appeared to be impaired both in phonological and orthographic skills, regardless of the measure (accuracy or processing time). However, compared to the younger RL controls, Ph-DYS, but also S-DYS, were only found to be impaired in phonological skills, either in processing time (Ph-DYS) or in accuracy (S-DYS). Furthermore, the S-DYS's verbal IQ, and not their nonverbal IQ, was lower than that of Ph-DYS and of average readers. Verbal IQ is known to be linked to environmental variables (see for example, Siegel, 1991) as is word-specific knowledge (see for example, Stanovich et al., 1997) and this could explain the poor orthographic skills of S-DYS. This question will be reexamined later.

Reliability of the Soft Subtypes

Orthographic vs. Phonological Spelling Skills: Longitudinal Data

Subtypes were identified using the regression method on pseudoword and irregular-word processing time. As we noted earlier, it is important to establish the reliability of the observed differences on a given measure across different assessments of the same skill. To assess the reliability of the soft subtype classification, we examined the results obtained by the four groups of children (S-DYS, Ph-DYS, CA controls and RL controls) on other assessments of phonological and orthographic skills, namely, pseudoword vs. irregular-word accuracy scores in spelling. These spelling assessments included longitudinal data collected two and three years before the data that served to establish the subtypes, that is, when the children were 7 and 8. Along with Stanovich et al. (1997), we assumed that differences between Ph-DYS and S-DYS expand with development. Thus, we expected an increase in the differences between the two dyslexic groups as well as between each of these two groups and the average readers from age 7 to 10, with a greater phonological deficit for Ph-DYS and a greater orthographic deficit for S-DYS.

The children's spelling performance was analyzed with a 3 (Group: average readers vs. S-DYS vs. Ph-DYS) x 3 (Session: age 7 vs. 8 vs. 10) x 2 (Type of Item: irregular-word vs. pseudoword) repeated measures ANOVA, where Session and Type of Item were within-subject factors and Group was a between-subject factor. When a main Group effect was found, in order to compare the spelling results with the reading resuls, we used two-tailed t-tests. We compared the scores of the 7- 8- and 10-year-old Ph-DYS or S-DYS to those of the same-age average readers. We compared also the scores of the 7- 8- and 10-year-old Ph-DYS to those of the same-age S-DYS. Finally, we compared the scores of the children of the same reading level (8-year-old average readers vs. 10 year-old Ph-DYS and S-DYS). The results are presented in Table 3. Differences without a significance level were significant at $p < .01$ or better.

The analysis yielded significant main effects of Group, $F(2,42) = 34.37$, $MSE = 877.28$, Type of Item, $F(1,42) = 215.06$, $MSE = 420.85$, and Session, $F(2,84) = 227.07$, $MSE = 182.76$. Only the Session x Type of Item and the triple interaction were significant, $F(2,84$ and $4,84) = 19.58$ and 7.01, respectively. The triple interaction was mainly due to the fact that the orthographic-skill difference between the two groups of dyslexics and average readers, as well as between S-DYS and Ph-DYS, increased between the first and last test sessions.

S-DYS had a significantly lower score than Ph-DYS on irregular-word spelling only when they were 10 years-old, $t(24) = 2.20$, $p < .05$. S-DYS, but also Ph-DYS lagged systematically behind the average readers on irregular words. As expected, the most notable difference in orthographic expertise was between 10-year-old S-DYS and same age average readers, $t(27$ and $33) = 3.42$ and 3.24; 5.47 and 5.45; 7.97 and 5.33, for 7-, 8-, and 10-year-old S-DYS and Ph-DYS vs. same-age average readers, respectively.

For phonological skills, Ph-DYS, but also S-DYS, lagged behind average readers on pseudowords, $t(33$ and $27) = 3.55$ and 6.85; 3.26 and 5.49; 3.71 and 4.75, for 7-, 8-, and 10-year-old Ph-DYS and S-DYS vs. same-age average readers, respectively. Surprisingly, S-DYS obtained consistently lower scores than Ph-DYS on pseudoword spelling, but the difference between the two dyslexic groups reached the conventional significance level only on the last test session, when the children were 10 years-old, $t(24) = 1.93$, $.05 < p < .10$, 2.00, $.05 < p < .10$ and 2.52, $p < .05$. Finally, neither the 10-year-old S-DYS, nor the same-age Ph-DYS obtained a lower score than the younger RL controls on irregular words whereas unexpectedly lower scores for pseudowords were observed for S-DYS, $t(27) = 3.46$.

Table 3. Means (and Standard Deviations) for Dyslexics and Average Readers: Longitudinal Data for Spelling, Phonemic Awareness and Musical Awareness

	Controls n = 19	S-DYS n = 10	Ph-DYS n = 16
Irregular-Word Spelling (Mean Percentage of Correct Responses)			
7-years-old	19.30 (15.96)	1.67 (03.51)	4.69 (9.11)
8-years-old	47.36 (16.44)	13.33 (14.79)	19.80 (12.87)
10-years-old	83.34 (12.43)	42.49 (14.42)	56.77 (17.02)
Pseudoword Spelling (Mean Percentage of Correct Responses)			
7-years-old	80.00 (18.48)	21.50 (27.39)	46.88 (35.44)
8-years-old	91.00 (10.23)	45.83 (33.50)	69.53 (26.51)
10-years-old	96.05 (03.52)	67.92 (25.6)	86.19 (10.94)
Phonemic Awareness (Correct Responses; Maximum, 20)			
5-years-old	9.00 (7.36)	2.80 (4.47)	3.44 (5.67)
7-years-old	19.63 (0.76)	14.30 (7.02)	14.63 (6.02)
8-years-old	19.89 (0.31)	17.20 (3.99)	17.56 (3.84)
Musical Awareness (Correct Responses; Maximum, 18)			
5-years-old	11.26 (4.31)	10.20 (3.68)	9.44 (3.79)
7-years-old	14.89 (3.20)	13.20 (2.44)	14.19 (2.71)
8-years-old	16.79 (1.27)	13.90 (3.54)	14.37 (3.40)

Discussion. The most notable difference in the assessment of spelling orthographic skills was found between 10 year-old S-DYS and either same-age Ph-DYS or same-age average readers. These results support the hypothesis that dissociations increase with development (Stanovich et al., 1997), at least for orthographic deficit in S-DYS. None of the longitudinal spelling data showed that the Ph-DYS's phonological skills were poorer than those of S-DYS. We even observed worse phonological skills in S-DYS than in Ph-DYS. Moreover, as compared to RL controls, a phonological deficit emerged only for S-DYS.

Together with the results of the assessment of orthographic and phonological reading skills, the spelling results suggest that a phonological deficit is at the core of developmental dyslexia because only a phonological deficit emerged in the comparison between Ph-DYS or S-DYS and RL controls. The fact that this deficit emerged in processing time for Ph-DYS, and in accuracy, both in reading and in spelling, for S-DYS, suggests a trade-off between processing time and accuracy. The observed differences between speed and accuracy in phonological processing could be explained by the fact that the slowest dyslexics were the most accurate ones. These children may try to overcome their phonological disability by increasing processing time. Inversely, the fastest ones may choose rapidity over accuracy.

Phonological and Visual Short Term Memory

A specific deficit in phonological short term-memory was hypothesized for Ph-DYS. A specific visual short-term memory deficit that would prevent orthographic word-pattern acquisition was hypothesized for S-DYS. Mean scores are shown in Table 2. Ph-DYS were not significantly worse-off than S-DYS on phonological short-term memory, and S-DYS were not significantly worse-off than Ph-DYS on visual short-term memory. All the more, Ph-DYS, but also S-DYS lagged behind CA controls only on phonological short-term memory, $t(33 \text{ and } 27) = 3.98$ and 3.80. The same result was observed in the comparison with the younger RL controls, $t(33 \text{ and } 27) = 3.98$ and 3.84. These results did not support the hypothesized Ph-DYS-specific phonological deficit and S-DYS-specific visual deficit.

Phonological vs Musical Awareness: Longitudinal Data

One could also hypothesize that Ph-DYS -- but not S-DYS -- had a specific deficit in phonemic awareness. Thus, we examined the phonemic awareness skills of Ph-DYS relative to those of S-DYS and of average readers. To determine whether the deficit in phonemic awareness was speech-specific, we assessed the children's musical awareness. The tasks were given when the children were 5, 7, and 8. As for the spelling longitudinal data, analyses of variance were conducted on the Group factor (3 levels) and on the Session factor (3 levels). Whenever there was a main effect of Group, we used two-tailed t-tests to compared the scores of the 5- 7- and 8-year-old future Ph-DYS to those of the future S-DYS and of the same-age future average readers.

The results are shown Table 3. For the phoneme deletion task, significant effects of Group and Session were found, $F(2,42) = 9.19$, $MSE = 36.00$ and $F(2,84) = 122.18$, $MSE = 17.75$, but no significant interaction emerged. No significant difference was observed between the two future-dyslexic groups, whereas Ph-DYS, but also S-DYS, always obtained lower scores than average readers, whether they were 5, 7, or 8 years-old, $t(33 \text{ and } 27) = 2.47$ and 2.42, $p < .05$; 3.60 and 3.32; 2.64, $p < .05$ and 2.97; respectively. The results are quite different from the musical awareness task results, where only a significant difference between sessions was observed, $F(2,84) = 42.41$, $MSE = 7.12$. As for short-term memory, the results of the phonological and musical awareness tasks thus suggest that reading difficulties are speech specific regardless of the subtype of dyslexia.

GENERAL DISCUSSION

Four main goals were set for this study. First, assess the proportions of Ph-DYS and S-DYS in a population of French dyslexics. Second, examine the reliability of the classification into Ph-DYS and S-DYS using different measures of phonological and orthographic skills. Third, find out when dissociated profiles emerge. Fourth, determine whether Ph-DYS and S-DYS are connected to other specific underlying deficits.

Hard vs. Soft Subtypes

Concerning the hard cases, the present study and other studies based on accuracy (Castles & Coltheart, 1993; Genard et al., 1998; Manis et al., 1996) showed that a mixed deficit is the most common profile. The percentage of both hard dyslexic subtypes appeared to be low. This percentage was almost the same in the two French studies (26% in the Genard et al. study and 29% in the present study). However, these overall percentages hide the fact that the individual proportions of the two hard subtypes were not the same in English and French. The proportions of Ph-DYS and S-DYS were almost the same in the English studies. In French, there were fewer Ph-DYS than S-DYS with a cutoff method based on accuracy data (3% vs. 23%, in Genard et al. and 10% vs. 19% in the present study) but not with one based on processing time. In the latter case, as in the English studies based on accuracy scores, the proportions of French Ph-DYS and S-DYS were almost the same (16% vs. 19%).

With the regression-based method, high numbers of Ph-DYS and S-DYS have been found compared to CA controls. Moreover, most studies have noted more Ph-DYS than S-DYS profiles. This is true of the English studies based on accuracy scores (54.7% vs. 30.2% and 33.3% vs. 29.4% in Castles & Coltheart, 1993, and Manis et al., 1996, respectively) and of our French study based on processing time (51.6% vs. 32.3%). The reverse trend was reported in the other accuracy-based French study (4% vs. 56% in Genard et al., 1998).

The discrepancy between the results for chronological-age comparisons may be due to linguistic differences. Since grapheme-phoneme correspondences are more consistent in French than in English, French-speaking children may be in a better position than English-speaking children to overcome the difficulties associated with the mastery of the phonological reading route. Thus, the Ph-DYS profile should be rarer in French than in English, and this is what has been found in studies based on accuracy data (see the soft and hard subtypes in Genard et al., and the hard subtypes in the present study). However, the present French study based on processing time (see the soft subtypes above) revealed almost as many Ph-DYS as in the English studies which were only based on accuracy scores. These results suggest that most of the time the French Ph-DYS would be able to attribute to graphemes their appropriate phonemic correspondences. Their phonological deficit only showed up as slow pseudoword reading. This help us to understand the discrepancy between the French studies based on accuracy data (Genard et al., 1998) and those based on processing time (the present study).

With regard to reading-level comparisons, the most striking finding in the studies we reviewed (Genard et al., 1998, Manis et al., 1996; Stanovich et al., 1997) and in the present study, is that there is still a high number of soft Ph-DYS, with the S-DYS profile nearly disappearing. Thus, surface dyslexics appear to exhibit a pattern of late but not deviant development, whereas soft phonological dyslexics appear to deviate from the normal developmental pattern.

Reliability of Soft Subtype Classification

When the children were 10-years-old, a phonological deficit in Ph-DYS relative to S-DYS was only found on the defining measures (pseudoword processing time). An orthographic deficit in S-DYS relative to Ph-DYS was found on irregular-word processing time and irregular-word spelling accuracy. These results corroborated those obtained for soft subtypes using the regression method. However, some important points must be mentioned. First, an unexpected phonological deficit in S-DYS relative to Ph-DYS was found on pseudoword spelling accuracy. Second, compared to RL controls, although the S-DYS's and Ph-DYS's orthographic skills were not more impaired on any measure, the phonological skills of the Ph-DYS and even those of the S-DYS were deficient. This was found based on processing time for Ph-DYS, and based on accuracy scores, both for pseudoword reading and spelling, for S-DYS. Third, Ph-DYS and even S-DYS were impaired in phonological short-term memory relative to RL controls. The phonological impairment of the two dyslexic groups was therefore quite severe, since it emerged even relative to younger average readers. These results are more in line with the hypothesis that a phonological deficit is at the core of developmental dyslexia (see Rack et al., 1992; Siegel, 1993; Stanovich & Siegel, 1994), than with Castles and Coltheart's idea that "a clear double dissociation exists between surface and phonological reading patterns" (1993, p.174).

When Did the Dissociated Profiles Emerge?

Our longitudinal spelling data on orthographic skills showed that there was no significant difference between future S-DYS and future Ph-DYS in the early stages of spelling acquisition. However, at the age of 10, S-DYS lagged behind Ph-DYS. As well, the most significant difference in orthographic skills was found between 10-year-old S-DYS and same age average readers. These results are consistent with the hypothesis that dissociations increase with development (Stanovich et al., 1997), at least for orthographic skills. No similar trends were found for phonological skills. First, based on the results of the phonemic awareness task, although there were no significant differences between the two groups of future dyslexics, the phonological skills of both future Ph-DYS and S-DYS were found to be impaired with respect to those of future average readers at all ages (ages 5 to 8). Second, based on the spelling data, once again, both Ph-DYS and S-DYS were phonologically impaired relative to average readers at all ages, whereas the phonological skills of Ph-DYS were not found to be lower than those of S-DYS. A phonological deficit was thus observed in both Ph-DYS and S-DYS, even before the beginning of reading instruction. None of these longitudinal findings support the hypothesis that the difference in phonological skills between Ph-DYS and S-DYS increases with development, with Ph-DYS at a disadvantage. Unexpectedly lower phonological skills in S-DYS compared to Ph-DYS were even found, when they were 10 (on pseudoword spelling).

Are the Ph-DYS and S-DYS Profiles Connected to Specific Underlying Deficits?

As already stated, one could hypothesize that Ph-DYS have specific phonological deficits, particularly in phonemic awareness and in phonological short-term memory, whereas S-DYS suffer from a deficit in visual short-term memory that prevents them from acquiring the orthographic pattern of words. In fact, a specific deficit in phonological skills was found here for both Ph-DYS and S-DYS. On the one hand, whereas no significant difference between the two groups of dyslexics, whether on phonemic awareness or on phonological short-term memory was observed, for both tasks, Ph-DYS and S-DYS lagged behind average readers. On the other hand, for non-phonological tasks (visual short-term memory and musical awareness), no significant differences between the two dyslexic groups and the controls were found. These results are consistent with those obtained in previous studies (for phonemic vs. musical awareness, see Morais et al., 1984; for phonological vs. non-phonological short-term memory, see Brady et al., 1983; Liberman et al., 1982; McDougall et al., 1994; Rapala & Brady, 1990). They suggest that the deficit of dyslexics is speech-specific.

Overall, no convincing data has been found to support the hypothesis that profiles in developmental dyslexia are induced by different underlying deficits. What remains to be explained is the connection (1) between the phonological deficit in reading and spelling observed for both subtypes, which was severe here in that it was found even in comparison with younger children of the same reading level, and (2) between the orthographic deficit in reading and spelling observed for both subtypes, which increased with age, especially for S-DYS, but which seems to be less severe since it was no longer present in the comparison with RLs.

Tentative Explanations

The orthographic lexicon is thought to be built gradually through the phonological route (Ehri, 1998; Perfetti, 1992; Share, 1995). The most impressive argument that supports this assumption is that, even in languages with a deep orthography such as English and to a lesser extent French, effective early use of phonological skills predicts later reading achievement (English: Jorm, Share, MacLean & Matthew, 1984; Byrne, Freebody & Gates; 1992; French: Sprenger-Charolles & Casalis, 1996; Sprenger-Charolles, Siegel & Bonnet, 1998). These results suggest that the acquisition of phonological skills is a necessary step in building the orthographic lexicon. Consequently, if the phonological reading skills of Ph-DYS are impaired, their orthographic skills should also be so. This is indeed what we found. For all tasks and measurements, 10-year-old dyslexics were phonologically and orthographically deficient compared to CA controls. Moreover, the phonological deficit of both types of dyslexics was severe, since it was found even in the comparison with younger RL controls. This was not the case for the orthographic deficit. Finally, the longitudinal data pointed out a deficit in phonemic awareness for the two groups of dyslexics, both before and after they began to learn to read.

Phonological skills thus seem to be at the core of reading acquisition and of reading disabilities (Share, 1995; Stanovich & Siegel, 1994). This might be due to the fact that reliance on the phonological reading route permits pseudowords as well as known and unknown regular words to be read. Through comparisons of phonologically processed written-words and words that are part of their oral vocabulary, children can associate graphemes with phonemes. Even highly irregular words contain some regular grapheme-phoneme correspondences, and the irregularities are related to grapheme frequency. For example, the use of grapheme-phoneme correspondences in French leads to the pronunciation of the high-frequency word femme as /fem/. Knowing that the word /fem/ does not exist, but that the word /fam/ does, children can infer that the "e" must be read as /a/ and not /e/ in this word. Children may learn most of the relationships between orthography and phonology through this implicit procedure. Because of grapheme-phoneme correspondences and word frequencies, strong associations between orthographic and phonological units enable children to gradually construct their orthographic lexicon so they can take the orthographic reading route. Nevertheless, even when this reading route is functional, children may still rely on the phonological route, which becomes more and more efficient as the various associations between orthographic and phonological units are consolidated.

In this framework, as well as in the connectionist model proposed by Plaut, McClelland, Seidenberg, and Patterson, 1996, grapheme-phoneme consistency is the major factor in learning to read. This helps us understand the impact of orthographic transparency on the learning process. This learning scheme works better with shallow orthography than with deeper orthography (for a review, see Sprenger-Charolles, in press). However, to be able to correctly map graphemes to phonemes, or phonemes to graphemes, children have to rely on well-specified phonological representations (see Snowling, Goulandris & Defty, 1996). If the child's phonological representations are underspecified, then the connections between graphemes and phonemes will be difficult to establish. This may be true of dyslexic children shown to have deficient phonemic skills from the very early stage of reading acquisition. Not only can their phonological reading and spelling skills be expected to be impaired, but also and consequently, their orthographic skills.

This is a tentative explanation of why both Ph-DYS and S-DYS suffer from phonological and orthographic deficits. But the question of the origin of the two dissociated profiles still remains. It is not possible to explain the S-DYS profile entirely in terms of a developmental lag because the phonological skills of these dyslexics appear to be more impaired than those of RL controls. Also, the hypothesis that a visual impairment characterizes S-DYS was not supported here, at least not judging by the visual skill we tested. As stated earlier, low performance on irregular words may be due to a lack of print exposure, insofar as word-specific knowledge is normally acquired through reading (Stanovich et al., 1997). Some of the data we collected could support this idea. At the beginning of the study when the children were 5 years-old, there was no significant verbal or nonverbal IQ difference between the future Ph-DYS and the future average readers. However, the future S-DYS's verbal IQ was significantly lower than that of both future average readers and future Ph-DYS. Verbal IQ is known to be linked to experiential variables and more generally to social class (see for example Siegel, 1991). As already stated, our dyslexics as a group did not differ from average readers as to social background. However, we found a sharp difference between S-DYS and Ph-DYS: 81% of the Ph-DYS came from upper-middle-class homes, whereas this was the case for only 40% of the S-DYS.

We would like to tentatively suggest that environmental factors explain the observed dissociations. S-DYS as well as Ph-DYS appear to suffer from phonological impairment. However, the Ph-DYS in the present study were brought up in an environment likely to motivate them to read, in spite of the fact that this activity is difficult for them. Thus, they may build a sight vocabulary that is larger than the one their phonological skills would predict. This may also account for the fact that they try to overcome their phonological disability by increasing processing time. In contrast, because our S-DYS came from a lower social class than our Ph-DYS, they may not be encouraged as much to learn to read. Consequently, they may have limited experience with the written language, and also less incentive to overcome their difficulties. This could explain why, on the one hand, they had a more severe orthographic deficit than the Ph-DYS, and why, on the other hand, at the time when the phonological deficit of Ph-DYS relative to RL controls only showed up as slow pseudoword reading, the phonological deficit of S-DYS was still revealed by the low accuracy scores. Therefore, in developmental dyslexia, there may be a single underlying phonological impairment which could be subject to change over time, depending on environmental factors. The observed differences in dyslexic behavior seem to arise from strategic compensations rather than from different cognitive profiles.

REFERENCES

Beauvois, M. F., & Derouesné, J. (1979). Phonologica alexia: Three dissociations. Journal of Neurology, Neurosurgery and Psychiatry, 42, 1115-1124.

Béchennec, D. & Sprenger-Charolles, L. (1998). Literacy teaching in France. In D. Corson (Ed.), Encyclopedia of language and education. (vol. 2, pp.191-198). Dordrecht: Kluwer Academic Press.

Bradley, L., & Bryant, P. (1978). Difficulties in auditory organization as a possible cause of reading backwards. Nature, 271, 746-747.

Brady, S. A., Shankweiler, D., & Mann, V. A. (1983). Speech perception and memory coding in relation to reading ability. Journal of Experimental Child Psychology, 35, 345-367.

Bruck, M. (1992). Persistence of dyslexics' phonological awareness deficits. Developmental Psychology, 28, 874-886.

Bryant, P., & Impey, L. (1986). The similarities between normal readers and developmental and acquired dyslexics. Cognition, 24, 121-137.

Byrne, B., Freebody, P., & Gates, A. (1992). Longitudinal data on the relations of word-reading strategies to comprehension, reading time and phonemic awareness. Reading Research Quarterly, 27, 141-151.

Campbell, A., & Butterworth, B. (1985). Phonological dyslexia and dysgraphia in a highly literate subject: A developmental case with associated deficits of phonemic processing and awareness, Quarterly Journal of Experimental Psychology, 37a, 435-475.

Castles, A., & Coltheart, M. (1993). Varieties of developmental dyslexia. Cognition, 47, 149-180.

Catach, N. (1984). Les listes orthographiques de base du français (LOB): Les mots les plus fréquents et leurs formes fléchies les plus fréquentes. Paris: Nathan.

Coltheart, M., Curtis, B., Atkins, P., & Haller, M. (1993). Models of reading aloud: Dual route and parallel processing approaches. Psychological Review, 100, 589-608.

Coltheart, M., Masterson, J., Byng, S., Prior, M., & Riddoch, J. (1983). Surface dyslexia. Quarterly Journal of Experimental Psychology, 35, 469-595.

Deltour, J. J., & Hupkens, D. (1980). Test de vocabulaire actif et passif pour enfants (5 à 8 ans). Issy-les-Moulineaux: E.A.P.

Ehri, L. C. (1998). Grapheme-phoneme knowledge is essential for learning to read words in English. In J. L. Metsala, & L. Ehri (Eds.), Word recognition in beginning literacy (pp. 3-40). Mahwah, NJ: Erlbaum.

Fawcett, A. J., & Nicolson, R. I. (1994). Persistence of phonological awareness deficit in older children with dyslexia. Reading and Writing: An Interdisciplinary Journal, 7, 361-376.

Genard, N., Mousty, P., Content, A., Alegria, J., Leybaert, J., & Morais, J. (1998). Methods to establish subtypes of developmental dyslexia. In P. Reitsma, & L. Verhoeven (Eds.), Problems and interventions in literacy development (pp. 163-176). Dordrecht, The Netherlands: Kluwer.

Gougenheim, G., Michéa, R., Rivenc, P., & Sauvageot, A. (1964). L'élaboration du français fondamental (1er degré): Etude sur l'établissement d'un vocabulaire et d'une grammaire de base. Paris: Didier.

Hanley, J. R., Hastie, K., & Kay, J. (1992). Developmental surface dyslexia and dysgraphia: An orthographic processing impairment. Quarterly Journal of Experimental Psychology, 44a, 2, 285-319.

Hitch, G. J., Haliday, S., Schaafstal, A. M., Marten, J., & Schraagen, C. (1988). Visual working memory in young children. Memory and Cognition, 16, 2, 120-132.

Inizan, A. (1995). Analyse de la compétence en lecture (ANALEC). Issy-les-Moulineaux: E.A.P.

Jorm, A. F., Share, D. L., MacLean, R., & Matthiews, R. G. (1984). Phonological recoding skill and learning to read: A longitudinal study. Applied Psycholinguistics, 5, 201-207.

Lecocq, P. (1991). Apprentissage de la lecture et dyslexie. Liège: Mardaga.

Liberman, I. Y., Mann, V. A., & Werfelman, M. (1982). Children's memory for recurring linguistic and non-linguistic material in relation to reading ability, Cortex, 18, 367-375.

Lundberg, I. (1982). Linguistic awareness as related to dyslexia, In Y. Zotterman (Ed.), Dyslexia: Neuronal, cognitive and linguistics aspects (pp. 141-153). New York: Pergamon.

Lundberg, I., & Hoien, T. (1989). Phonemic deficits: A core symptom of developmental dyslexia. The Irish Journal of Psychology, 10, 4, 579-592.

Mann, V. A. (1993). Phoneme awareness and future reading ability. Journal of Learning Disabilities, 26, 259-269.

Mann, V. A., & Liberman, I. Y. (1984). Phonological awareness and verbal short term memory: Can they presage early reading problems? Journal of Learning Disabilities, 17, 592-599.

Manis, F. R., Seidenberg, M. S., Doi, L. M., McBride-Chang, C., & Peterson, A. (1996). On the basis of two subtypes of developmental dyslexia. Cognition, 58, 157-195.

McDougall, S., Hulme, C., Ellis, A., & Monk, A. (1994). Learning to read: The role of short term memory and phonological skills. Journal of Experimental Child Psychology, 58, 112-133.

Morais, J., Cluytens, M., & Alegria, J. (1984). Segmentation abilities of dyslexics and normal readers. Perceptual and Motor Skills, 58, 221-222.

Morton, J., & Patterson, K. E. (1980). A new attempt at an interpretation or an attempt at a new interpretation. In M. Coltheart, K. E. Patterson, & J. C. Marshall (Eds.), Deep dyslexia: Neuropsychological and cognitive studies of phonological reading (pp. 91-118). London: Routledge, Kegan Paul.

Paap, K. R., & Noel, R.W. (1991). Dual-route models of print to sound: Still a good horse race. Psychological Research, 53, 13-24.

Perfetti, C. (1992).The representation problem in reading acquisition. In P. Gough, L. Ehri, & R. Treiman (Eds.), Reading acquisition (pp. 107-143). Hillsdale, NJ: Erlbaum.

Plaut, D. C., McClelland, J. L., Seidenberg, M. S., & Patterson, K. E. (1996). Understanding normal and impaired word reading: Computational principles in a quasi-regular domain. Psychological Review, 103, 56-115.

Rack, J. P., Snowling, M. J., & Olson, R. K. (1992). The nonword reading deficit in developmental dyslexia: A review. Reading Research Quarterly, 27, 29-53.

Rapala, M. M., & Brady, S. A. (1990). Reading ability and short term memory: The role of phonological processing. Reading and Writing: An Interdisciplinary Journal, 2, 1-25.

Raven, J. C. (1976). Coloured progressive matrices. Sets A, Ab, B. Oxford: Oxford Psychologists' Press Ltd.

Savigny, M. (1974). Bat-Elem. Issy-les-Moulineaux: Editions de Psychologie Appliquée.

Seymour, P. H. K. (1986). Cognitive analysis of dyslexia. London/New York: Routledge & Kegan Paul.

Share, D. L. (1995). Phonological recoding and self-teaching: Sine qua non of reading acquisition. Cognition, 55, 151-218.

Siegel, L. S. (1991). Alice in IQ land or why IQ is still irrelevant to learning disabilities. In P. G. Aaron & R. M. Joshi (Eds.), Reading disabilities: Diagnosis and component processes (pp. 71-84). Dordrecht: Kluwer Academic Publishers.

Siegel, L. S. (1993). Phonological processing deficits in reading as the basis of a reading disability. Developmental Review, 13, 246-257.

Snowling, M. J., Bryant, P., & Hulme, C. (1996). Theoretical and methodological pitfalls in making comparisons between developmental and acquired dyslexia: Some comments on A. Castles & M. Coltheart (1993). Reading and Writing: An Interdisciplinary Journal, 8, 444-451.

Snowling, M. J., Goulandris, N., & Defty, N. (1996). A longitudinal study of reading development in dyslexic children. Journal of Educational Psychology, 88, 653-66.

Sprenger-Charolles, L. (in press). Linguistic processes in reading and spelling. The case of alphabetic writing systems (English, French, German and Spanish). In T. Nunes, & P. Bryant (Eds.), Handbook of children's literacy. Kluwer Academic Publishers B.V.

Sprenger-Charolles, L., & Casalis, S. (1996). Lire. Lecture/écriture: Acquisition et troubles du développement. Paris: Presses Universitaires de France.

Sprenger-Charolles, L., Siegel, L. S., & Bonnet, P. (1998). Phonological mediation and orthographic factors in reading and spelling. Journal of Experimental Child Psychology. 68, 134-155.

Stanovich, K. E., & Siegel, L. S. (1994). Phenotypic performance profile of children with reading disabilities: A regression-based test of the phonological-core variable-difference model. Journal of Educational Psychology, 86, 24-53.

Stanovich, K. E., Siegel, L. S., & Gottardo, A. (1997). Converging evidence for phonological and surface subtypes of reading disability. Journal of Educational Psychology, 89, 114-127.

Temple, C. M., & Marshall, J. C. (1983). A case study of developmental phonological dyslexia. British Journal of Psychology, 74, 517-533.

Valdois, S., Gérard, C., Vanault, P., & Dugas, M. (1995). Peripheral developmental dyslexia: A visual attentional account? Cognitive Neuropsychology, 12, 31-67.

Wagner, R. K., Torgesen, J. K., & Rashotte, C. A. (1994). Development of reading related phonological processing abilities: New evidence of bi-directional causality from a latent variable longitudinal study. Developmental Psychology, 30, 73-87.

Wimmer, H. (1993). Characteristics of developmental dyslexia in a regular writing system. Applied Psycholinguistics, 14, 1-33.

Wimmer, H. (1996). The early manifestation of developmental dyslexia: Evidence from German children. Reading and Writing: An Interdisciplinary Journal, 8, 171-188.

APPENDIX

Words, Regularity Levels 1, 2, 3 and 4
1. abri, arbre, lavabo, livre, marmite, minute, pile, porte, sable, samedi, table, tomate
2. écharpe, four, marche, moule, ouvre, poche, poudre, riche, ruche, sourire, tache, tour
3. acide, école, facile, figue, local, longue, merci, noirci, page, partage, plage, potage
4. album, attention, compte, femme, noël, noeud, pied, poêle, punition, scie, sept, short

Pseudowords, List 1: Regularity Levels 1, 2 and 3
1. lople, mirpe, sinope, tanepi
2. loumi, moube, sulche, turche
3. lurce, marpige, silge, tocir

Pseudowords, List 2
-tirbul, puldir, dirpul, bultir
-tribul, pludir, dripul, blutir
-tibulo, pudiro, dipulo, butiro

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FOOTNOTES

1. The 17 lost participants did not differ as to their kindergarten reading level, verbal and nonverbal IQs from the 43 children remaining in the sample.